Sports Nutrition: A Review of Selected Nutritional Supplements For Endurance Athletes

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Abstract

The use of supplements as ergogenic aids is common among endurance athletes. Some of these nutritional products have been shown to be valuable additions to a training regimen; however, others have been shown to at best produce equivocal results. This article reviews several supplements currently popular among endurance athletes. Included in the discussion are Panax ginseng, Eleutherococcus senticosus, L-carnitine, **choline**, coenzyme Q10, pyridoxal-alpha-ketoglutarate, pyruvate, and performance drinks. (Alt Med Rev 1997;2(4):282-295)

Introduction

The use of supplements as ergogenic aids is common among endurance athletes. Because there is widespread belief among athletes that special nutritional practices will enhance their achievements in competition, many athletes utilize one or more supplements to gain a competitive advantage. Some of these nutritional products can be valuable additions to a training regimen; however, others at best produce equivocal results. Marketing claims for many of these products are abundant in product literature, magazines distributed by the health food industry, magazines sold to the lay public, and information available on the Internet. Unfortunately, what is sometimes missing or misrepresented are the Òbottom line resultsÓ produced from supplementation. This article reviews some of the supplements currently promoted in this market in an effort to determine which contribute to maximizing

results. Included in the review are Panax ginseng, Eleutherococcus senticosus, L-carnitine, choline, coenzyme Q10, pyridoxal-alpha-ketoglutarate (PAK), pyruvate, and performance drinks.

Panax ginseng

Panax ginseng, also known as Panax schinseng, is a member of the family Araliaceae. In Mandarin Chinese it is called Ren Shen but is commonly referred to as Korean or Chinese ginseng. Several closely related species are also often sold as ginseng. These include: Panax quinquefolium (American ginseng); Panax notoginseng, also known as Panax pseudoginseng (Himalayan ginseng), and Panax japonicum (Japanese ginseng). Ginseng was used traditionally as a tonic for a broad range of medical conditions. It was believed to be a revitalizing agent capable of enhancing health and promoting longevity.

Soviet scholars, beginning in the early 1950Õs, were the first to establish that many Araliaceae family plants, especially Panax ginseng, are adaptogens.[1] Adaptogens, among their many properties, are thought to promote regeneration of the body after stress or fatigue and to rebuild strength. Because of its reputation as an adaptogen, Panax ginseng is among the most popular botanical supplements used by athletes.

Many animal studies with Panax ginseng, or its active components, have demonstrated an enhanced response to physical or chemical stress.[2-6] In rats, aqueous suspensions of Panax ginseng roots were tested for anti-stress activity by the Òmice swimming endurance testÓ and anabolic activity by noting gains in body weight and muscle. A significant increase in mice swimming time was shown by ginseng-fed rats compared to the control group.[7]

In animal models, administration of ginseng has been shown to impact several hormones which might impact performance. High doses of ginseng have been reported to increase blood testosterone level.[8] Experiments indicate the binding of corticosteroid to certain brain regions is increased in adrenalectomized rats given ginseng saponin.[9] Ginseng saponin has also been reported to act on the hypothalamus and/or hypophysis, stimulating ACTH secretion which results in increased synthesis of corticosterone in the adrenal cortex.[10]

While studies with animals have been compelling, ginsengÕs value as an ergogenic aid in humans is equivocal.[11] Extracts of Panax ginseng are reported to increase plasma total and free testosterone, dihydrotestosterone, FSH, and LH levels in infertile males.[12] The addition of ginseng root extract to a multivitamin base is reported to have improved subjective parameters in a population exposed to the stress of high physical and mental activity.[13] In a double-blind, randomized, crossover study, 50 healthy males received two capsules of a preparation containing ginseng extract, dimethylaminoethanol bitartrate,

vitamins, minerals, and trace elements, or two capsules of placebo every day for six weeks. The total work load and maximal oxygen consumption during exercise were significantly greater after the ginseng preparation than after placebo. The authors also noted decreased plasma lactate levels, carbon dioxide production, and heart rate during exercise in participants receiving the ginseng preparation.[14]

Morris et al investigated the effects on performance of a ginseng saponin extract (8 or 16 mg/kg body weight) ingested daily for 7 days. Although time to exhaustion was significantly less during the pre-supplementation control trial than during the placebo and ginseng periods, no significant difference was found between the placebo and the ginseng trials.[15] It should be noted the duration of the supplementation period was only one week in this trial. Since ginseng, as a tonic, has been used historically for prolonged time periods and since positive results have been reported following a longer period of supplementation, a longer trial might have demonstrated an ergogenic effect.

Scientific results supporting the use of Panax ginseng as an ergogenic aid, although equivocal, are promising. Because of the anec-dotal reputation and allure this plant holds, it is likely to continue to be utilized by athletes. The quality of available ginseng preparations can vary greatly, so it is imperative that Panax ginseng is purchased from a reputable source. A typical dose for general tonic effect would contain at least 25 mg of the saponin ginsenoside.[16] Panax ginseng contains 2-3% ginsenosides, so a dose of 8-12 grams of crude herb, assuming it is of high quality, would provide adequate saponin content. Because of the variability in quality of Panax ginseng available, Pizzorno and Murray recommend utilizing a preparation standardized for ginsenoside content. The dosage for a product standardized to 5% ginsenosides would be 500 mg per day, while a product standardized to 14% ginsenosides would be about 180 mg.[16] If utilizing ginseng for a prolonged period of time, some authors have recommended discontinuing supplementation periodically for 2-week intervals.

Eleutherococcus Senticosus

Eleutherococcus senticosus is also known botanically as Acanthopanax senticosus. It is also a member of the Araliaceae family. In China, the plant is called Ci Wu Jia; however, it is most commonly referred to as Siberian ginseng. Because of its wide availability and lower cost, the dried root and rhizome is commonly used as a ginseng substitute; however, ginsenosides characteristic of Panax species are not found in the roots of Eleutherococcus senticosus.[16]

Eleutherococcus senticosus is classified as an adaptogen, and is believed to promote recovery and improve endurance. It has a long history of use in Chinese herbal medicine where it was used to enhance general health, longevity, appetite, and memory. Soviet

scientists, beginning in the late 1950Õs, because of the rarity of Panax ginseng, shifted the focus of their research to other members of the Araliaceae family in order to find suitable substitutes. Four adaptogenic plants were identified, studied, and finally introduced into therapeutic practice between 1955 and 1964. Eleutherococcus senticosus was considered to be the most important of these substitutes.[17] Reports indicate Eleutherococcus was used routinely by both Soviet Olympic athletes and military officers.

Extracts of Eleutherococcus prolong the exercise time to exhaustion in swimming rats,[18] and modulate changes of the hypophyseo-adrenal system in rats under extreme conditions.[19] Farnsworth et al reviewed results of clinical trials of Eleutherococcus in humans. The data gathered indicated ingestion of extracts from the plant increased the ability to accommodate to adverse physical conditions, improved mental performance, and enhanced the quality of work under stressful conditions, such as during athletic performance.[20]

Dowling et al, however, concluded supplementation of Eleutherococcus senticosus had no ergogenic effect on the measured parameters associated with submaximal and maximal aerobic exercise tasks. They investigated the effect on performance during submaximal and maximal aerobic exercise in twenty highly trained distance runners randomly assigned in matched pairs to either an Eleutherococcus or placebo group. Participants consumed either 3.4 ml of extract or placebo daily for six weeks. During the 8-week double-blind study subjects completed five trials of 10-minute runs on a treadmill at their 10 km race pace and a maximal treadmill test. No significant differences were observed between Eleutherococcus and placebo supplemented groups for heart rate, oxygen consumption, respiratory exchange ratio, and rating of perceived exertion during the 10 km and maximal treadmill tests.[21]

Recently, Eleutherococcus senticosus has received attention in the popular press under the name of Ci Wu Jia. Trials on Ci Wu Jia and performance have been conducted in exercise physiology laboratories by researchers at the Institute of Nutrition and Food Hygiene, Beijing, China, and the University of North Texas Health Science Center, Fort Worth, Texas. The trials were sponsored by PacificHealth Laboratories, Inc., which is the manufacturer of a standardized extract of Ci Wu Jia, marketed as Endurox, and the holder of a patent for the use of Ci Wu Jia to enhance stamina and physical performance during exercise and to enhance recovery following cessation of exercise. All reports appearing in the popular press on Ci Wu JiaÕs impact on performance have been based on information provided by this manufacturer.

Ci Wu Jia reportedly has a carbohydrate-sparing action, shifting metabolism to a higher utilization of fat for energy. The carbohydrate shift is also reported to delay lactic acid buildup associated with muscle fatigue. Reports indicate Ci Wu Jia might slightly reduce heart rate during exercise and recovery. Participants usually consumed 800 mg of the

standardized extract daily for two weeks.

Overall the evidence for an ergogenic effect from Eleutherococcus senticosus is fair. Evidence published by Dowling et al. indicates Eleutherococcus senticosus was not a useful herb for improving exercise performance in highly trained athletes. Because the benefits claimed by PacificHealth Laboratories, Inc. for their product are to date unpublished, these claims should be viewed with a healthy degree of skepticism. The reported benefits Russian athletes received from supplementation remain the more persuasive evidence to date on the ergogenic potential of this plant.

Recommended doses vary depending on the form of Eleutherococcus utilized. The dose of a 1:1 fluid extract (33% ethanol) usually is between 2.0-4.0 ml one to three times per day; however, doses up to 16.0 ml have been used. A standardized 20:1 solid concentrate is also available. In this form, a minimum recommended dosage would be 300 mg per day, equivalent to six grams of powdered root. Better results might be experienced at higher doses. In order to avoid accommodation, Eleutherococcus should be used for no longer than 60 consecutive days, followed by a period of 2-3 weeks of abstinence before resuming supplementation.[20]

Carnitine

Carnitine is promoted as a supplement needed to improve the bodyÕs ability to use stored fat as fuel. Supplementation purportedly enhances lipid oxidation, increases VO2 max, and decreases plasma lactate accumulation during exercise.

Carnitine is a tri-methylated amino acid, roughly similar in structure to **choline**. The synthesis of carnitine begins with methylation of lysine by S-adenosylmethionine. Cofactors required for optimal synthesis include magnesium, iron, ascorbic acid, folic acid, methylcobalamin, betaine, pyridoxal 5'-phosphate, and niacin.

Carnitine is located in the mitochondrial membrane, and is a cofactor needed for the transformation of free long chain fatty acids (LCFAÕs) into acyl-carnitines for subsequent transport into the mitochondrial matrix. Inside the mitochondria, LCFAÕs are metabolized into energy through the process of beta-oxidation.

Several investigators have suggested L-carnitine supplementation might benefit athletes. Swart et al investigated the effect of giving 2 grams/day of L-carnitine for six weeks to seven male marathon athletes. They reported improved running speed of 5.68% and decreased average oxygen consumption and heart rate in the treadmill test following supplementation. The authors suggest that for carnitine to be effective as an ergogenic aid several pre-conditions must be met. These include having an adequate supply of lipids

available as fuel, shifting metabolism toward utilization of fats as an energy source, and having a relative shortage of available endogenous carnitine. Because average free and total plasma carnitine levels were below the normal ranges prior to supplementation, the L-carnitine might have helped to overcome a relative endogenous deficiency for the participants involved in this study.[22]

Siliprandi et al, in a double-blind cross-over experiment of 10 moderately trained male subjects, gave either 2 grams of L-carnitine or placebo orally one hour prior to exercise. Supplementation with L-carnitine induced a significant post-exercise decrease of plasma lactate and pyruvate and a concurrent increase of acetylcarnitine.[23] Vecchiet et al randomly gave 2 grams of L-carnitine or a placebo to subjects one hour before they began exercise. At the maximal exercise intensity, treatment with L-carnitine increased both maximal oxygen uptake and power output. The authors also reported, at similar exercise intensities, oxygen uptake, carbon dioxide production, pulmonary ventilation, and plasma lactate were reduced in participants receiving L-carnitine.[24]

While some of the results with L-carnitine supplementation have been promising, not all research is in agreement. Heinonen, in his review of carnitine and physical exercise, came to the following conclusions regarding carnitine supplementation: its impact on performance in athletes is equivocal; it does not enhance fatty acid oxidation, spare glycogen or postpone fatigue during exercise; it does not stimulate pyruvate dehydrogenase activity; and it does not reduce body fat or help with weight loss.[25]

Vukovich et al found chronic carnitine supplementation, 6 g/day, resulted in no differences in VO2, respiratory exchange ratio, heart rate, or carbohydrate and fat utilization. They also reported muscle carnitine concentration at rest was unaffected by supplementation.[26]

Barnett et al similarly reported carnitine supplementation, 4 g/day for 14 days, while effective at increasing plasma total acid soluble and free carnitine concentrations, had no significant effect on muscle carnitine concentrations.[27] Cooper et al, after loading athletes with L-carnitine for 10 days prior to a marathon, found that carnitine supplementation, while abolishing the exercise-induced fall in plasma-free carnitine and increasing the production of acetylcarnitine, resulted in no detectable improvement in performance.[28]

Colambani et al investigated the effects of L-carnitine supplementation on metabolism and performance of endurance-trained athletes during and after a marathon run. In a double-blind crossover field study, seven male subjects received 2 grams of L-carnitine two hours before the start of a marathon run and again after 20 km of running. Although the administration of L-carnitine was associated with a significant increase in the plasma concentration of all analyzed carnitine fractions, significant changes in running time, plasma concentrations of carbohydrate metabolites (glucose, lactate, and pyruvate), of fat metabolites (free fatty acids, glycerol, and beta-hydroxybu-tyrate), of hormones (insulin,

glucagon, and cortisol), and of enzyme activities (creatine kinase and lactate dehydrogenase) were not observed.[29]

Although available data on L-carnitine as an ergogenic aid is not compelling, under some experimental conditions pretreatment has favored aerobic processes. It is possible L-carnitine might only exert a beneficial effect when there are actual deficiencies. Availability of fat as a substrate for fuel might also impact on the ability of carnitine to act as an ergogenic aid. Supplementation of 2 grams one hour prior to intensive exercise might provide some benefits; however, based on the mixed results and the cost of the supplement, chronic administration of L-carnitine might not be justified.

Choline

Choline supplements have been advocated as a means of preventing the decline in **choline** reported to occur during exercise. **Choline** in the diet primarily consists of phosphatidylcholine, which after absorption by the intestinal mucosa, is metabolized to **choline** in the liver. Most **choline** is re-phosphorylated to phosphatidylcholine; however, a small amount of **choline** is carried to the brain via the blood stream, where it is converted to acetylcholine, a chemical messenger required for adequate nerve impulses and memory storage and retrieval.

Conlay et al reported that running a 26-km marathon reduced plasma **choline** by approximately 40%.[30] The decline has been proposed to reduce acetylcholine levels resulting in a reduction in the transmission of contraction-generating impulses across skeletal muscle.31 It has been proposed this reduction might negatively affect endurance performance.[30,31]

Von Allworden et al investigated the effect of lecithin on the plasma **choline** concentrations during continuous strain in 10 top level triathletes (four women and six men). The participants received either a placebo or 0.2 g lecithin/kg body mass, one hour before each exercise. Bicycle exercise without lecithin supply decreased plasma **choline** concentrations in all the triathletes, on average by 16.9%. When lecithin was given before exercise, average plasma **choline** concentrations remained at the same level as the initial values. In trial II, with 13 adolescent runners (three girls and 10 boys), mean plasma **choline** concentrations remained stable when running without supplementation of lecithin.[32]

Spector et al found trained cyclists do not deplete **choline** during supramaximal brief or prolonged submaximal exercise, nor do they benefit from **choline** supplementation, as **choline** bitartrate (2.43 g), to delay fatigue under these conditions.[33]

No evidence to date provides compelling justification for supplementation of **choline** as an ergogenic aid. Its potential efficacy for improving physical performance remains largely theoretical.

Coenzyme Q10 (ubiquinone)

Coenzyme Q10 (CoQ10), because of its role in mitochondrial energy production, is reputed to enhance performance; however, no studies have demonstrated a significant improvement in any aspect of athletic performance.

Karlsson et al reported muscle CoQ10 levels were positively correlated to exercise capacity and marathon performance in the individuals they biopsied.[34] Porter et al gave 150 mg/day of CoQ10 orally for two months to a group of middle-aged men. Although supplementation resulted in increased circulating blood levels of CoQ10 and improved perceived level of vigor, no improvement in aerobic capacity was found.[35] Braun et al found 100 mg per day of CoQ10 supplemented for eight weeks produced no measurable effect on cycling performance, VO2 max, submaximal physiological parameters, or lipid peroxidation.[36] Laarsonen et al found oral ubiquinone was ineffective as an ergogenic aid in both young and older trained men.[37]

Based on available research, CoQ10 appears to have no value as an ergogenic aid.

Pyridoxal-alpha-ketoglutarate

Pyridoxal-alpha-ketoglutarate (PAK) consists of pyridoxine (54%) and alpha-ketoglutarate (46%). It is thought to improve the generation of high energy phosphate bonds, such as ATP or GTP. In addition, an enhanced level of alpha-ketoglutarate, along with pyridoxal 5'-phosphate, in the mitochondria might enhance the transamination of pyruvate to alanine, which may prevent or reduce lactic acid formation.[38]

Administration of PAK has been shown to decrease plasma concentration of lactate in response to isometric exercise in a group of insulin-dependent diabetic patients.[39] The administration of 30 mg/kg of PAK for 30 days has been reported to increase VO2 max (a measurement of maximal aerobic power) and to decrease lactic acid accumulation during short supramaximal work loads. The administration of alpha-ketoglutarate or pyridoxine separately did not alter VO2 max significantly.[38]

Linderman et al investigated the use of PAK and sodium bicarbonate individually and in

combination, on short-term maximal exercise capacity in eight cyclists. Oral tablets of sodium bicarbonate and PAK were given in doses of 200 mg/kg and 50 mg/kg, respectively. The investigators found no significant differences between treatments in the ability to sustain maximum power during the exercise trial; however, the best results obtained were from individuals utilizing both PAK and bicarbonate. PAK supplementation alone did not improve a participantÕs ability to sustain maximum power.[40]

For athletes wishing to experiment with this supplement, the recommended dose is 1800-3000 mg/day, depending on body weight.

While PAK might be complementary to athletic training, particularly in conjunction with sodium bicarbonate, available information is limited. PAK supplementation appears to positively influence some physiological parameters associated with enhanced aerobic performance; however, to date this supplement has not been shown to produce a Òbottom lineÓ result of improving actual performance.

Pyruvate

Supplementation of pyruvate is becoming popular with athletes due to reports of its endurance and weight loss enhancing effects. Pyruvate is a stable salt form of pyruvic acid, the naturally occurring end product in the metabolism of carbohydrates. It is stabilized by the addition of either sodium, potassium, calcium, or magnesium to pyruvic acid. Pyruvic acid occurs naturally in the diet in fruits and vegetables. Red apples are possibly the best source, with an estimated 450 mg of pyruvic acid per apple.

Pyruvate is a three-carbon compound containing a carboxylic acid and a ketone group. During the process of glycolysis, glucose is converted to pyruvate. Pyruvate is then either converted to acetylCoA, for entry into the citric acid cycle, under aerobic conditions or to lactate under anaerobic conditions. PyruvateÕs mechanism of action for weight loss and for enhancing endurance is unknown.

In published research, pyruvate has usually been given in conjunction with dihydroxyacetone. Stanko et al have reported this combination to be useful in weight loss routines. They investigated the effect of partially, isocalorically substituting pyruvate and dihydroxyacetone for glucose in obese women. Participants were placed on severely restrictive hypocaloric diets for 21 days while housed in a metabolic ward. In one study, when compared to placebo (P), participants fed dihydroxyacetone and pyruvate (DHAP) showed greater weight loss (DHAP = 6.5 ± 0.3 kg, P = 5.6 ± 0.2 kg) and fat loss (DHAP = 4.3 ± 0.2 kg, P = 3.5 ± 0.1 kg).[41] In another trial, pyruvate and dihydroxyacetone, given as approximately 20% of energy intake, reduced the reaccumulation of body weight (1.8 ± 0.2 kg vs 2.9 ± 0.1 kg,) and fat (0.8 ± 0.2 kg vs 1.8 ± 0.2 kg) associated with refeeding

after a calorie restricted diet.[42]

Stanko et al also reported pyruvate alone to be an effective addition to a weight loss program. Participants were obese women housed in a metabolic ward consuming a 4.25-MJ/d liquid diet for 21 days with or without pyruvate partially, isoenergetically substituted for glucose. Participants fed pyruvate showed greater weight loss (5.9 ± 0.7 kg vs placebo = 4.3 ± 0.3 kg) and fat loss (4.0 ± 0.5 kg vs placebo = 2.7 ± 0.2 kg).[43] The reports indicate pyruvate had no impact on enhancing nitrogen balance, serum protein concentrations or lean body mass in these subjects.[41-43]

Published studies were conducted on obese women consuming restricted calorie diets of either 500 or 1000 calories per day, so current claims regarding weight loss should not be extrapolated to athletes or other populations on normal or high calorie diets until more information is available. Additionally, in the published trials pyruvate has been substituted for glucose; a substance which impacts fat metabolism in overweight individuals because of its role in insulin secretion. It is possible under similar circumstances, that partially, isocalorically substituting protein or fat for glucose might have produced similar if not better results.

Pyruvate has been reported to increase the time required to reach exhaustion and to decrease perceived exertion. In the published studies, pyruvate was given in relatively high amounts in conjunction with dihydroxyacetone (DHAP). In two studies, untrained males received either 100 grams of pyruvate and dihydroxyacetone or 100 grams of a glucose polymer derived from the hydrolysis of cornstarch as a placebo for 7 days. Arm endurance was 133 ± 20 minutes after placebo and 160 ± 22 minutes after DHAP.[44] Leg endurance was 66 ± 4 minutes after placebo and 79 ± 2 minutes after DHAP.45 Muscle glycogen, determined by biopsy, at rest and exhaustion did not differ between placebo and DHAP.[45] Plasma free fatty acids, glycerol, and beta-hydroxybutyrate were similar during rest and exercise for placebo and DHAP in both studies.[44,45] Supplementation of a DHAP mixture has also been reported to decrease the perceived level of exertion.[46]

Feeding DHAP for seven days appeared to increase submaximal endurance in untrained athletes; however, it is unresolved whether similar results would be obtained with trained athletes. In the published studies, 25 grams of pyruvate were given with 75 grams of dihydroxyacetone per day; however, in the lay press Stanko has been quoted as saying, ÒWe see a linear response between 2 and 5 grams a day and then the response plateaus. In other words, the response with 10 or 15 grams or more is the same as with 5 grams.Ó This information has not been published in the scientific literature to date, nor has any information been published on the effects on endurance of pyruvate supplementation without dihydroxyacetone .

Commercially available pyruvate is manufactured by Med-Pro Industries. Their dosage

recommendation is 2-5 grams per day, taken with food. It has also been suggested that better results might be obtained by spreading the five grams into two or three divided doses. Since reported results on endurance were obtained in trials comparing DHAP against a glucose polymer, the only justifiable conclusion is that subjects consuming 100 g of DHAP rather than 100 g of hydrolyzed corn starch (a substance with no nutritional value) experienced better endurance. Prior to making a positive recommendation on this product, research should be published suggesting 2-5 grams of pyruvate added to the diet of trained athletes improves performance. Only questionable evidence is available suggesting high-dose pyruvate, in combination with dyhydroxyacetone, acts as an ergogenic aid. No research exists to support claims of ergogenic action for pyruvate supplementation at the recommended dose of 2-5 grams.

Performance Drinks

Performance drinks are commonly consumed as an ergogenic aid during endurance sports activities. These drinks are designed to maintain normal hydration, electrolyte balance and blood glucose levels during exercise. Current evidence indicates ingestion of performance drinks during exercise enhances athletic performance and normalizes markers of thermoregulation. A variety of beverages formulated to provide fluid, carbohydrates, and electrolytes during and following exercise are commercially available. These beverages commonly contain 4-8% carbohydrate (as glucose, fructose, sucrose or maltodextrins), and small amounts of electrolytes (most often sodium, potassium, and chloride). Contrary to popular belief, rates of sweating and urine flow are not influenced by fluid ingestion during exercise.[47]

Studies have shown that 5-10% solutions of glucose, glucose polymers (maltodextrins), and other simple sugars have suitable gastric emptying characteristics for the delivery of fluid and moderate amounts of carbohydrate substrate. The optimal concentration of electrolytes, particularly sodium, remains unknown. Most currently available sports drinks provide a low level of sodium (10-25 mmol/L) in recognition that sodium intake can promote intestinal absorption of fluid as well as assist in rehydration.[48]

Exercise and dehydration result in increases in core temperature, body fluid osmolality, and heart rate; losses of plasma and other body fluid volumes; and depletion of glycogen. Each of these homeostatic disturbances can be ameliorated by fluid consumption during exercise.[49]

During exercise, water and electrolytes are lost from the body in sweat. Sweat rate is determined primarily by the metabolic rate and environmental temperature and humidity. Under some conditions, sweat rate can exceed the maximum rate of gastric emptying of ingested fluids. If this occurs, some degree of dehydration is observed. Excessive

replacement of sweat losses with plain water or fluids with a low sodium content following prolonged exercise has resulted in hyponatraemia, so sodium replacement is considered essential for postexercise rehydration.[50]

For moderate intensity exercise, water ingestion 30-60 minutes prior to exercise seems to minimize homeostatic disturbances; however, at higher intensities of athletic performance, this probably has little effect.49 During exercise, both ingestion of water and carbohydrate beverages have been shown to minimize homeostatic disturbances. In subjects allowed to **drink** ad libitum a carbohydrate-electrolyte beverage (4.85% polycose, 2.65% fructose) or distilled water during three hours of continuous exercise in the heat (31.5 degrees C), no significant differences between drinks were observed for rectal temperature, heart rate, or sweat rate during exercise.[51] Hickey et al observed no differences in thermoregulatory responses in individuals consuming either carbohydrate beverages or water.[52]

The efficacy of a given **drink** is limited by the rate of absorption of fluid from the intestines, which is in turn limited by gastric emptying. Several factors influence gastric emptying; including exercise intensity and the carbohydrate composition of the solution.[53] Gastric emptying rate might also be influenced by the caloric content, volume, osmolality, temperature, and pH of the ingested fluid; metabolic state and biochemical individuality of the athlete; and the ambient temperature.[54]

The caloric content of the ingested fluid might be the most important variable governing gastric emptying rate. At rest and during running, water has a faster gastric emptying time than all other drinks. Gastric emptying is progressively slowed as the caloric content of the fluid increases.[53] During moderate exercise, gastric emptying occurs at a rate similar to that during rest; however, more intense exercise appears to inhibit gastric emptying. Evidence indicates beverages containing less than 10% carbohydrate have gastric emptying rates the most similar to water.[55] Davis et al report drinks containing less than or equal to 8-10% carbohydrate are made available for dilution in body fluids at similar rates, and should be similar in replenishing body fluids lost in sweat during exercise.[56]

Several other factors have been shown to impact gastric emptying. Isotonic drinks appear to empty quickly throughout exercise, whereas gastric emptying rate of hypertonic drinks has been shown to decrease over time.[57] Fat is believed to delay gastric emptying; however, medium chain triglycerides (MCT) might not inhibit gastric emptying as most fat does. Research indicates drinks containing both MCT and maltodextrins have faster gastric emptying times than drinks containing only maltodextrins.[58]

It has been suggested maltose might be a superior source of carbohydrate for endurance athletes. Wagenmakers et al have suggested ingestion of an 8% solution of maltodextrin or sucrose every 15 minutes during exercise might provide optimal fluid and carbohydrate replacement.[59] The rates of gastric emptying and the peak rates of exogenous carbohydrate

oxidation are not significantly different between maltose and glucose.[60]

Burgess et al reported ingestion of 13 g carbohydrate per hour did not improve performance during prolonged moderate intensity cycling;[61] however, most studies report ingestion of carbohydrate beverages has a beneficial effect on performance. Carbohydrate ingested during exercise appears to be readily available as a fuel for working muscles, at least when the exercise intensity does not exceed 70-75% of maximum oxygen uptake.[62] Rating of perceived exertion is reported to be higher in athletes consuming water than in athletes consuming carbohydrate drinks.[51] For exercise leading to exhaustion in less than 30 minutes, carbohydrate ingestion is not effective in minimizing homeostatic perturbations or improving exercise performance;[49] however, for exercise of longer duration, ingestion of performance beverages appears to enhance performance. Davis et al found 275 ml of a 6% carbohydrate-electrolyte beverage consumed every 20 minutes maintained blood glucose and enhanced performance better than water during endurance cycling.[63] Bacharach et al compared the effects of orange-flavored drinks containing 0%, 6.4%, and 10% carbohydrate. The solutions, 3 ml/kg body weight, were given double blind and counter-balanced at time zero and every 20 minutes during exercise. Blood glucose and lactate, and temperature were similar for all solutions; however, performance improved with consumption of a carbohydrate **drink** during exercise. The best results were obtained with ingestion of a 10% carbohydrate **drink**.[64]

Eight well-trained men cycled for up to 255 min at a power output corresponding to VO2 at lactate threshold (approximately 68% VO2 max) on three occasions separated by at least one week. Subjects drank 5 ml/kg body weight of either a water placebo, or a liquid beverage containing a moderate (6% carbohydrate) or high (12% carbohydrate) concentration of carbohydrate beginning at minute 14 of exercise and every 30 minutes thereafter. Exercise time to fatigue was shorter in subjects receiving placebo (190 min), as compared to 6% carbohydrate (235 min) and 12% carbohydrate (234 min) beverages.[65]

Twelve subjects were exercised to exhaustion on a cycle ergometer at a workload corresponding to 70% of maximum oxygen uptake. On one trial, no drinks were given and on the other trials subjects drank 100 ml every 10 minutes. Median exercise time was greatest (110.3 min) for individuals receiving a **hypotonic** glucose-electrolyte solution (90 mmol/l glucose; 60 mmol/l Na+; 240 mosmol/kg), followed by individuals receiving an isotonic glucose-electrolyte solution (I: 200 mmol/l glucose; 35 mmol/l NA2; 310 mosmol/kg) (107.3 min), water (93.1), and no **drink** (80.7). Significant treatment effects were also observed for heart rate, rectal temperature, and serum osmolality.[66]

Twelve highly trained male runners ran 15 km at self-selected pace on a treadmill in warm conditions to demonstrate differences in physiological responses, fluid preferences, and performance when ingesting sports drinks or plain water before and during exercise. One hour prior to the start of running, an equal volume (1,000 ml) of either water or a 6% or an

8% carbohydrate-electrolyte **drink** was ingested. Blood glucose was significantly higher 30 minutes following ingestion of 6% and 8% carbohydrate-electrolyte beverage compared to water, significantly lower at 60 minutes post ingestion with both sports drinks than with water, but similar after 7.5 km of the run for all beverages. During the first 13.4 km, oxygen uptake and run times were not different between trials; however, the final 1.6-km performance run was faster with both carbohydrate-electrolyte drinks compared to water.[67]

Research indicates a sugar **drink** immediately prior to exercise can impair performance. Carbohydrates will invoke an insulin response which increases the likelihood of hypoglycemia occurring during exercise. According to Lamb, a fall in blood glucose will result from the ingestion of glucose solutions fed 15-45 minutes before prolonged exercise; however, the consumption of 18-50% solutions of glucose or glucose polymers five minutes before prolonged exercise has potential for improving endurance performance.[49]

Many experts recommend consuming a beverage high in carbohydrates within one hour after exercise. Exercise-induced depletion of muscle glycogen levels can be rapidly restored by glucose ingestion. According to Burke, provided adequate carbohydrate is consumed it appears that the frequency of intake, the form (liquid versus solid), and the presence of other macronutrients does not affect the rate of glycogen storage.[68] During the post-exercise recovery period, ingesting a carbohydrate-electrolyte beverage is effective in minimizing physiological disturbances. Subjects **drink** more; plasma volume increases to a higher level; plasma osmolality, glucose, and potassium are greater; and body weight increases more with ingestion of carbohydrate beverages than with water.[51]

The optimum frequency, volume, and composition of drinks will vary widely depending on the intensity and duration of the exercise, the environmental conditions, and the physiology of the individual. However, in general, isotonic beverages with either glucose, glucose polymers, or maltodextrins as the carbohydrate source produce the best results. Prior to exercise, only water should be consumed. Drinking carbohydrate solutions 15-60 minutes prior to exercise should be avoided since it can impair performance; however, ingestion immediately prior to beginning exercise might be beneficial. This is because once endurance exercise is started, insulin is generally not increased, so carbohydrates will likely be available as energy substrates. The staggered ingestion of performance drinks will be beneficial when exercise duration exceeds 30 minutes; however, during shorter duration exercise and especially weight lifting, there appears to be no additional benefit in ingesting anything other than water.

Conclusion

Based on available information, evidence remains mixed but promising on the supplementation of Panax ginseng and Eleutherococcus senticosus. L-carnitineÕs role as

an ergogenic aid remains somewhat of a mystery. The mixed results reported in the literature and the high cost of the supplement make it difficult to justify chronic administration of 2 grams per day. No evidence to date supports the supplementation of **choline** as an ergogenic aid. CoQ10Õs failure in several studies to demonstrate any performance-enhancing effect should end any debate or recommendations concerning routine administration of this nutrient as an ergogenic aid. Although PAK supplementation has been shown to enhance certain parameters associated with aerobic exercise, it has not yet demonstrated bottom-line results of improved performance. Although evidence suggests pyruvate acts as an ergogenic aid in high dosages in combination with dyhydroxyacetone, available evidence does not support claims of an ergogenic action for pyruvate supplementation at a dose of between 2-5 grams. The staggered ingestion of performance drinks should be a routine practice in endurance exercise activities of greater than 30 minutes duration.

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